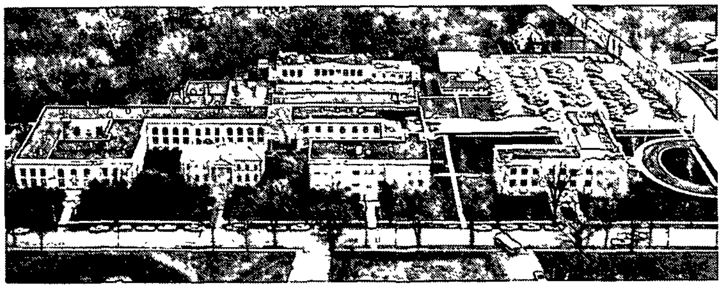

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IMPULSE DRYING: HOW MILLS CAN TAKE ADVANTAGE OF IT

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IMPULSE DRYING: HOW MILLS CAN TAKE ADVANTAGE OF IT

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ABSTRACT

Passing a moist or wet sheet of paper or board through a high temperature press nip causes an extremely rapid dewatering process called impulse drying. Although impulse drying is not yet commercially available, its potential impact on papermaking is very significant. This process will use much less energy than a conventional dryer and remove water twice as fast as a wet press or 1000 times as fast as a cylinder dryer in their respective solids ranges. Impulse drying will also produce exceptional densification and bonding, even for coarse, difficult to bond furnishes. Such a dryer may be used to increase capacity, replace parts of the pressing and drying sections, save energy, improve product quality, and allow substitution of lower cost furnishes. All of these advantages can be taken singly or in almost any combination. This paper describes many of the single advantages and stresses the need for mill-wide systems studies to fully realize the multiple advantages of impulse drying. Finally, the availability of the databases for this purpose and the importance of starting now to consider impulse drying in future capital projects is pointed out.

INTRODUCTION

In papermaking, most of the water is removed by simple drainage elements which usually raise the web solids to about 20%. The remaining small amount of water is removed first by pressing and then by drying. Pressing "squeezes" the sheet to reduce volume and force water from it. Drying evaporates water from the sheet. These processes have evolved over the years and now perform about as well as fundamental limitations allow. Hence, significant improvements are not to be expected.

In response to the need for better web consolidation, several so-called high-intensity drying or pressing and drying processes have evolved (2,3,4,5). All of these involve elements of combined pressing and drying and several have been developed under the umbrella of press drying. Press drying has its roots in the very early work by Mason, reported by Moore (6), who developed a process for producing hardboard from a very crude TMP furnish. Central to this process and its subsequent development for paper (3) is the notion that flow of lignin and hemicellulose is critical to product properties and can only occur if the fiber temperature is elevated for a fairly long time. It is apparently this premise that has led to press drying concepts that require at least modest pressures for relatively long time periods. This presents a formidable hurdle for commercial application. In contrast, Wahren's early work on impulse drying (5) was directed almost totally to achieving extraordinarily high water removal rates with little early attention to property development. It is now recognized, however, that even the very short exposure times of impulse drying can produce both high water removal rates and the lignin and hemicellulose flow desired for property development with some furnishes (7).

Background on Impulse Drying

In impulse drying, the sheet is subjected to conditions typical of wet pressing in a wide-nip press while heat is simultaneously supplied to one side from a very hot surface. In practice, this could be achieved with a wide-nip press with an externally heated, plain press roll operating in a single-felted configuration. Typically, pressures range from 1.0-5.0 MPa, hot surface temperatures from 150-500 C, and nip residence times from 15 to 100 ms. This brief exposure to intense conditions invokes dewatering and densifying mechanisms not exhibited by any conventional process. Mild forms of some of these new features were recognized by Gottwald, Halsey and Williams (2) in their pioneering work on a form of press drying. Devlin (1), Sprague and Burton (8) and Burton, Sprague, and Ahrens (9) have identified the full spectrum of mechanisms in impulse drying.

The most important of these new mechanisms is the generation of a vapor-filled zone next to the hot surface and a liquid-filled zone next to the felt. These two zones fill the sheet so liquid is displaced into the felt as the vapor zone grows. An appreciable amount of water is removed as liquid by this mechanism, leading to extremely rapid dewatering and excellent energy efficiency. A heat pipe-like heat transfer process causes rapid heating through the vapor zone next to the hot surface. This gives rise to thermal softening and to the flow of lignin and hemicellulose, much as reported for the much longer press drying processes (10). Water carried in and on the fibers in the vapor zone is prevented from evaporating by hygroscopic effects until the nip opens and the vapor pressure begins to drop. At that point, water held by the fibers leaves by a flash evaporation process. The fibers then collapse either as a result of Campbell's forces or due to the external structural load imposed by the press, or both. This portion of the fiber network becomes extremely well bonded and dense, leading to excellent surface properties on the finished sheet. These same mechanisms are very effective in promoting bonding in normally difficult to consolidate furnishes, offering the opportunity of substituting lower cost fiber in many grades. However, the application of impulse drying to webs with high flow resistance (heavy basis weight, high fines content, extensive refining) may be limited by delamination produced by residual high vapor pressures in the sheet at the end of the nip.

As this brief overview points out, impulse drying offers benefits of many types. These can be taken singly or in combination. Some affect only paper machine operation, others affect the entire mill. As a consequence, the benefits for a particular mill may be very site-specific, requiring a detailed and broad analysis for that installation. The purposes of this paper are to emphasize the need for such analyses, to point out the databases required for them and to show that they are now timely. It will draw heavily on a performance overview for several grades presented by Sprague (11), and papers on impulse drying of newsprint (12) and linerboard (13) by Lavery.

Impulse Dryer Applications

For replacing or augmenting drying cylinders

For initially well pressed sheets (45-50% solids), Lavery has reported impulse drying rates in the range from 3000-8000 kg/hr/m^2 for both newsprint (12) and linerboard (13). At these high rates, a single impulse dryer can replace about half of the dryer cans on a linerboard machine and virtually all of them on a newsprint machine. In this direct substitution role, the impulse dryer can save capital and space. It will also save some energy and improve properties, as noted later.

For dryer (or press) limited machines, all drying cylinders can remain except the one or two that must be removed to make space for the impulse dryer. In this configuration, the impulse dryer provides incremental capacity to improve productivity without requiring major building or machine changes. Energy savings and property improvements will be realized here as well.

For replacing wet presses

As the ingoing moisture ratio increases beyond about 1.0 (wetter sheets), water removal rates increase dramatically and in such a fashion that outgoing solids levels remain virtually constant (Figure 1). This insensitivity to the amount of water carried into the nip is a direct consequence of the vapor displacement mechanism. As a further consequence, discussed later, the specific energy consumption in this wet pressing moisture range is low enough to justify the use of high grade energy for water removal. These results clearly show that a single impulse dryer can be used to replace one or two presses and, perhaps, even the first. Hence, the impulse dryer is not restricted to following a full press section but may, instead, replace part or all of it.

For replacing both presses and dryer cylinders

As noted in Figure 1, the outgoing solids level is quite insensitive to the ingoing solids level. Hence, an impulse dryer installed in a second or third press position will produce exit dryness levels very nearly as high as it would if placed at the beginning of the dryer section. This means the impulse dryer can do the work of the displaced press or presses plus that of a good portion of the dryer section, as well. Figure 2 shows an example where one impulse dryer replaces two presses and half of the dryer cans in a 125 g/m^2 linerboard application. If properly selected, this impulse dryer could provide some measure of incremental capacity, as well.

All of the applications discussed above can be further enhanced by adding steam boxes ahead of the impulse dryer to preheat the web. Raising the sheet initial temperature from 25 C to near 100 C may increase the amount of water removed by as much as 50% (11). Preheating promotes mostly liquid water removal, so the energy efficiency is correspondingly increased, even when the energy for preheating is taken into account.

For energy conservation

Impulse dryers are extremely energy efficient, due in large part to the vapor displacement mechanism. Specific energy consumption values for various initial solids are shown in

Figure 3 for 125 g/m^2 linerboard sheets. Over the initial solids range from about 25-40%, as little as 500 kJ are enough to remove one kilogram of water. In contrast, cylinder drying from 45% solids requires about 3600 kJ/kg.

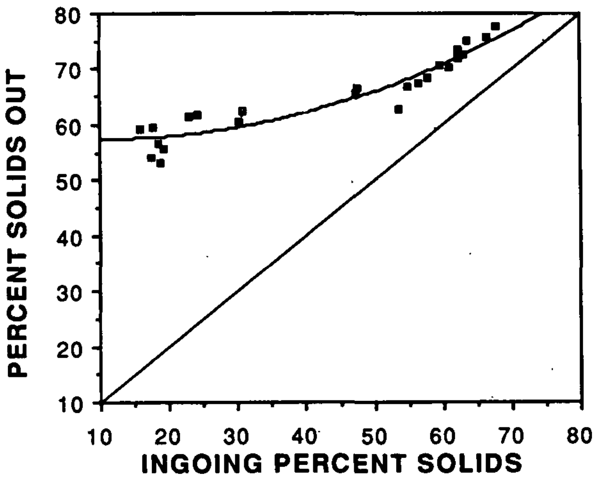

Fig. 1. Water removal performance observed for impulse drying 125 g/m^2 virgin kraft linerboard sheets. Impulse drying performed at 315°C, 4800 kPa peak pressure for 30 milliseconds. All sheets preheated to 82°C. Data for sheets drier than 58% solids were taken on the reverse side of a previously impulse dried sheet.

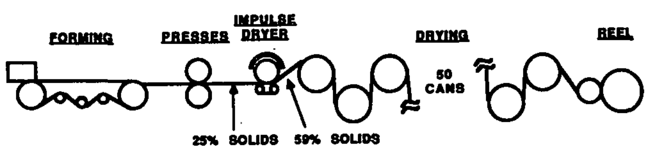

Fig. 2. One possible machine configuration implementing impulse drying. Calculations based on 125 g/m^2 linerboard produced at 2000 ft/minute, with 5 ft diameter cylinder dryers. A cylinder drying rate of 5 pounds of water per square foot of heat transfer surface was assumed in the calculations. Without the impulse dryer, two additional presses and so additional drying cylinders would be required.

In most cases, the impulse dryer exit solids is well below the 94% required for the finished product. Hence, some cylinder dryers must remain. The above energy figures account only for the energy used in the impulse dryer. The combined energy of impulse and cylinder drying from 30-50% solids to 94% solids is about one third that required for cylinder drying from 45% solids. Total energy consumption climbs with increasing initial moisture level and finally reaches typical commercial consumption levels at about 20% solids.

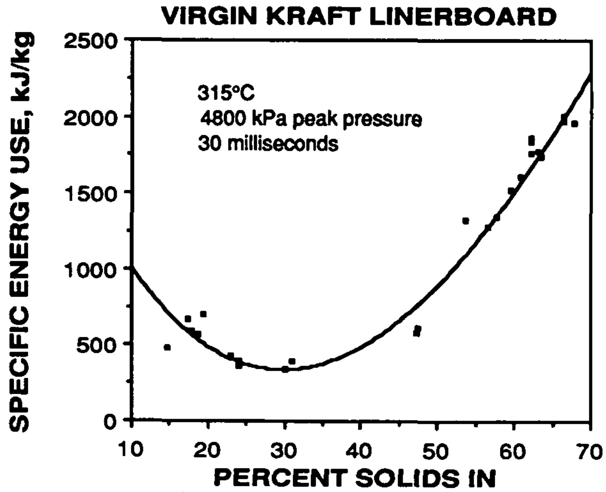

Fig. 3. Specific energy use for linerboard measured by the lithium chloride displacement method. All data for 125 g/m^2 sheets preheated to 82°C before impulse drying at 315°C and a peak pressure of 4800 kPa for 30 milliseconds. Data for sheets drier than 58% solids were taken on the reverse side of a previously dried sheet.

Because impulse dryers will use a higher grade of energy than cylinder dryers, the total energy cost will not drop as much as energy consumption. Specific costs will depend on the types and relative amounts of energy actually used, but in all cases will favor impulse drying.

For strength improvement with traditional furnishes

When substituted directly into an existing papermaking system, impulse drying will produce all of the benefits noted above. When compared to traditional web consolidation systems, impulse drying provides significant incremental density development as well. This is very important, since so many end-use performance characteristics of paper increase directly with density, as noted by Malmberg (14). For most furnishes, density increases nearly linearly with solids out of the impulse dryer (Figure 4).

Most of the traditional strength property-density relationships hold for impulse dried sheets. Thus, the higher densities lead directly to higher tensile and compressive strength (Figures 5a and b, respectively). In all cases, the strengths and densities correspond and reach values well above those for the conventionally processed control sheets.

The ability of impulse drying to promote densification and bonding can be used to improve product performance for traditional grades made from traditional furnishes. The degree of incremental performance will depend almost totally on the degree of impulse drying, i.e., the solids out of the dryer. Hence, the gain is controlable. As we shall see later, this feature can be used to make products with standard commercial quality from lower cost furnishes.

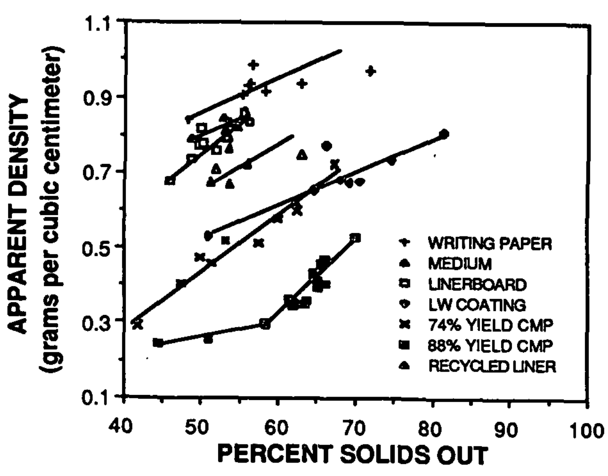

Fig. 4. IPC apparent density development for several commercially important grades. Medium, linerboard, recycled liner and CMP grades all at 125 grams per square meter, newsprint and lightweight coating rawstock at 50 grams per square meter and writing paper at 80 grams per square meter. Data include peak pressures at 2760 and 4800 kPa, temperatures from 205 to 315°C, and nip residence times between 15 and 30 milliseconds. All sheets initially at 50% solids and 20°C.

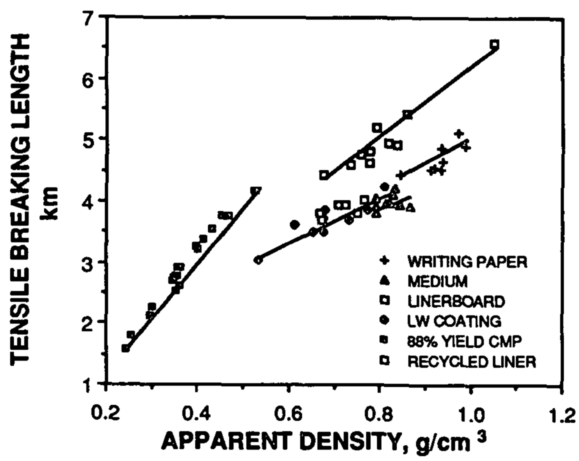

Fig. 5a. Tensile strength development with densification for several commercially important grades. Medium, linerboard, recycled liner and CMP grades all at 125 grams per square meter, newsprint and lightweight coating rawstock at 50 grams per square meter and writing paper at 80 grams per square meter. Data include peak pressures at 2760 and 7800 kPa, temperatures from 205 to 315°C, and nip residence times between 15 and 30 milliseconds. All sheets initially at 50% solids and 20°C.

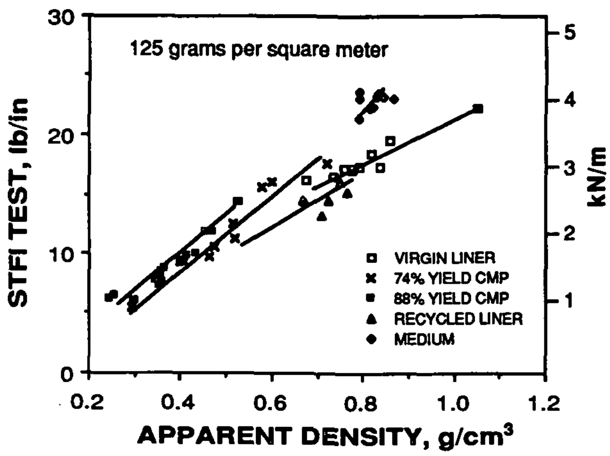

Fig. 5b. STFI compression test for medium and several alternative linerboard furnishes. Medium, linerboard, recycled liner and CMP grades all at 125 grams per square meter. Data include peak pressures at 2760 and 4800 kPa, temperatures from 205 to 315°C, and nip residence times between 15 and 30 milliseconds. All sheets initially at 50% solids at 20°C.

For surface property improvement

Impulse drying improves a number of surface properties that are expected, in turn, to improve conversion and printability. All of these improvements are the combined result of thermal softening of the fibers and the fiber collapse induced by flash evaporation. By virtue of these mechanisms, roughness of the sheet surface next to the hot roll is reduced by 40-60%. Roughness of the surface next to the felt remains constant or increases slightly due to felt imprinting (Figure 6). Two-sided drying reduces roughness on both surfaces. For acceptable smoothness of the final product, some calendering may still be required, however.

For developing optical properties

The optical properties of many paper products are critical to their final application. Usually, processes which increase density tend to degrade optical properties such as brightness and opacity. Hence, impulse drying would be expected to perform poorly in this regard because of its great ability to densify. Fortunately, however, the traditional reduction of these properties with density does not occur (Figure 7), so the losses are modest, usually only a few percentage points. This favorable departure from the usual opacity-density relationships is believed to be due to the unique z-direction density profile in impulse dried sheets (8).

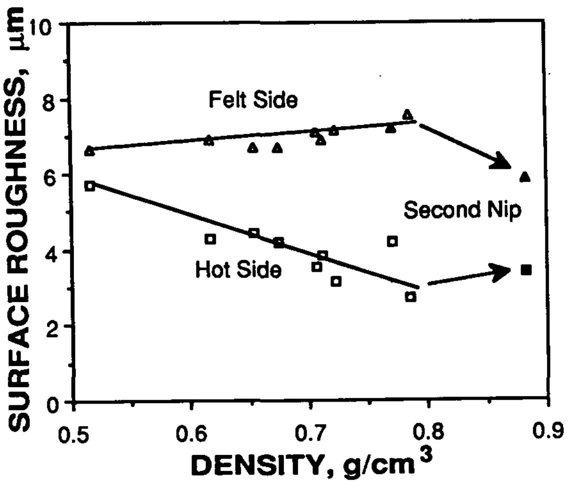

Fig. 6. Surface roughness after impulse drying 50 g/m^2 newsprint sheets. Data include peak pressures at 2760 and 4800 kPa, temperatures from 205 to 315°C and nip residence time between 15 and 30 milliseconds. All sheets initially at 50% solids and 20°C.

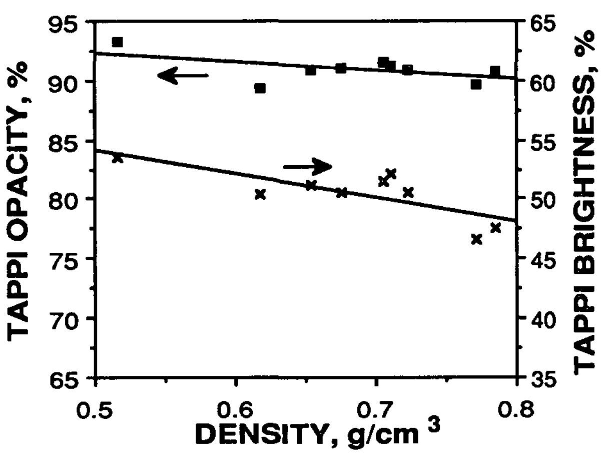

Fig. 7. Brightness and opacity after impulse drying 50 g/m^2 newsprint. Data include peak pressures of 2760 and 4800 kPa, temperatures from 205 to 315°C and nip residence times between 15 and 30 milliseconds. All sheets initially at 50% solids and 20°C.

In many cases, impulse drying would allow substitution of lower cost furnishes for the optical grades. These furnishes would densify less to produce greater opacity but still achieve acceptable levels of other properties.

For reducing raw material costs

Premium furnishes such as low-yield kraft are flexible and strong. As a consequence, they conform and bond readily under conventional papermaking practices to produce strong sheets. Impulse drying can improve the performance of such furnishes, but not dramatically, as shown in Figure 5. In contrast, lower cost furnishes tend to be stiff and coarse. Some carry appreciable residual lignin, and some are partially or fully hornified. All are less conformable and more difficult to bond. Some yield poor paper performance when used as a significant fraction of a furnish processed conventionally. These factors limit the use of such furnishes in current practice, despite the attractiveness of lower cost, greater availability and ease of dewatering.

Impulse drying can be used effectively to increase the utilization of these lower cost furnishes. First, such furnishes are easy to dewater, so impulse drying readily achieves high solids levels (Figure 4). Correspondingly high density levels are also achieved, even for these stiff materials. Finally, high density corresponds directly to good bonding and, therefore, to good strength levels, as evident in Figure 5. Dundore (7) showed that impulse drying of an 88% yield chemimechanical spruce pulp increased both relative bonded area and specific bond strength. The strength of the resulting sheets was limited by the intrinsic fiber strength and not by bonding, a remarkable fact for such a crude furnish. This dramatizes the ability of impulse drying to develop good properties from low cost materials.

All of the data used to illustrate the ability of impulse drying to promote bonding in crude furnishes were derived from 100% substitutions. Clearly, substituting for only a portion of a high quality furnish would yield even better performance. Included in the list of possible substitutions or modifications are reduced refining, increased yield in conventional pulping lines, increased use of hardwoods or secondary fibers, substitution of mechanical pulps for chemical pulps and so on. Finally, new additives or increased use of additives may be possible with impulse drying.

In addition to direct cost savings and improved availability, increased use of crude furnishes could significantly impact pulp mill capacity, energy costs, complexity and other economic factors. Some level of whole-mill modeling will be necessary to fully assess the overall benefits of such changes.

For special effects

Impulse drying is a very intense process which invokes new mechanisms for dewatering and densifying a wet paper web. As such, it offers major advantages in the conventional sense of performance of paper machines. Impulse drying also induces strong z-direction gradients in temperature, pressure, density and phase. In most cases, the nip is opened before these gradients can subside, and so the density gradient tends to remain in the finished sheet. This density profile is important to sheet properties and may explain some of the unusual density-property relationships found in impulse dried sheets. These include higher than expected opacities, increased tear-tensile ratios, and increased bending stiffness. These relationships have not been studied sufficiently for them to be predicted or even effectively utilized in papermaking, but they remain as potentially significant additional advantages of the process. In grades where these properties are paramount, laboratory work could provide the basis for achieving increased performance through use of impulse drying.

For moisture and property profile leveling

Water removal rates and energy consumption in impulse drying are closely linked to ingoing moisture ratio and hot surface temperature. Pressure is a relatively unimportant variable and can be ignored. Nip residence time will be fixed for a given operation. Hence, the degree of moisture profile leveling depends mostly on the interplay among moisture ratio, temperature and the mode of temperature control used on the hot roll.

A wet streak will appear as a local increase in moisture ratio. For constant temperature operation, typical of all laboratory studies, water removal rate and heat flux at the roll surface will both increase in proportion to the increase in moisture ratio. The locally higher water removal rate will be quite effective in leveling the moisture streak (Figure 1), but the result is not perfect. Constant power density control will allow a local temperature drop under a wet streak. This will give poorer moisture leveling than constant temperature control. Actively controlling the surface temperature profile using moisture sensing and a segmented power delivery system should provide very effective leveling control.

All impulse dryer performance data show that solids out of the dryer is a very good indicator of density and, therefore, of properties. Hence, moisture leveling should contribute to strength leveling as well. However, end-of-machine measurements may not deliver a level moisture profile at the outlet of the dryer. Property uniformity could suffer as a result.

An impulse dryer will provide nearly full sheet restraint over the full machine width. This may provide a nearly level CD strength profile by avoiding the shrinkage-induced droop that occurs in conventional machines.

Summary - The Systems Viewpoint

Up to this point, this paper has described several possible applications of impulse drying, each designed to realize a single advantage. Each of these is important in its own right, but it should be evident that any given application can effectively realize several of the potential advantages at one time. To cite two extremes, one could use an impulse dryer strictly for incremental capacity or one could use it to gain some measure of almost all of the individual advantages outlined above.

In the first case, the relatively high capital cost of an impulse dryer would be offset by the avoided costs of rebuilding the machine and the building to house it. Productivity will provide added incentive for the project. Despite the impressive gains that can be realized from this approach, it ignores many of the potential benefits of impulse drying. Even for this simple add-on installation, there will be additional benefits in energy savings, improvements in properties (which could be taken as raw material cost reductions), profile leveling and so on.

In the more complex case, gains may be sought in several areas at one time, each being very important to overall mill objectives. It is quite possible, for example, to replace parts of both the pressing and drying sections, increase capacity, reduce energy costs, improve product properties, improve CD uniformity and reduce raw material costs, all with one installation. Some of the advantages may require capital expenditures in other parts of the mill. Clearly, in such a case the payoff and tradeoff picture is complex, requiring a detailed analysis to achieve the best balance for the given mill situation. In some cases, the project may be phased, bringing in a few of the advantages as each phase is completed. This very site-specific situation is likely to be typical of impulse drying applications.

Site-specific and detailed analysis of this kind will require several things. First, a very broad general performance database for impulse drying will be necessary for the preliminary analysis phase. This database is being generated as part of the overall project sponsored jointly by the Members of The Institute of Paper Chemistry (IPC) and the U. S. Department of Energy (DOE). Much of it is already available. Hence, this type of consideration can and should be given to long range capital projects now being considered. Doing so will allow proper consideration of and timing for use of impulse drying, even in projects for which initiation is several years in the future.

At a second and more detailed phase, most cases will require additional data that are very specific to the mill, product and furnish base in question. Quite often this information will be proprietary and generated specifically for the case under consideration. In many cases, perhaps most, whole-mill modeling at some level will be needed to optimize mill configurations that include impulse dryers. The need for this type of information and the high degree to which it will be site-specific is a direct consequence of the wide array of payoffs from impulse drying. The small cost of these special tests and analyses will be amply justified, however, by the additional benefits derived from impulse drying as a result.

Impulse drying is an exciting new web consolidation process that can probably be implemented commercially on the wide-nip pressing technology now in place or readily available. It is an emerging technology that is being developed rapidly in laboratories and on pilot systems in several locations. Commercial application can be expected in the next few years.

ACKNOWLEDGMENTS

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